A Paleomagnetic Study
of a core of Upper Ordovician Limestone
from the area near Minerva, Kentucky

Presented in partial fulfillment of requirements
for the Department of Geology and Mineralogy

Advisor's Signature

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ABSTRACT

A paleomagnetic study of 20 feet of borehole core of Upper Ordovician age has revealed several geomagnetic polarity reversals at various depths. No correlation is found between lithology (which varies from limestone to shale) and polarity.

Experimental determination of the best field for removal of soft viscous components of natural remanence was found to be 600 Oe. After demagnetization, the average inclination of the paleomagnetic field was found to be 26.0°. This mean inclination was calculated for the upper twenty feet of core using ten cores with reversed polarity with an inclination of 40.0° and eight cores of normal polarity with an inclination of 12.1°. From this a calculated paleolatitude of 13.7° S. for North America during the Upper Ordovician is in fairly close agreement with results previously obtained. A virtual geomagnetic pole is simply interpolated from Middle Ordovician and Upper Silurian data.

INTRODUCTION

The objective of this senior thesis is the paleomagnetic investigation of part of a borehole core of Upper Ordovician shale, siltstone, and limestone. This paper deals only with the twenty-foot interval contained in the Fairview Formation at depths of 20 to 40 feet. A concurrent senior thesis dealing with the twenty-foot interval from 40 to 60 feet, is also contained in the Fairview Formation. The forty feet of core contains three certain reversals of the axial geocentric depole, nine probable reversals, and four possible reversals.

Core segments were drilled with the help of an aluminum jig designed by Dr. H. C. Noltimier and Bob Bartman and constructed by Bartman with a

"C" channel base supplied by the Batelle Memorial Institute. A picture of this jig is to be found in Bartman's senior thesis.

Core CA-38, which is catalogued in the Department of Geology and Mineralogy as core 70ZA, was drilled in the Fairview Formation (Upper Ordovician, Maysvillian) near Minerva, Kentucky, by Cominco American, Inc. Figure 1 (Sweet, Harper, Zlatkin, 1974) shows the location of the borehole.

GEOLOGIC SETTING

The Fairview Formation is described by William F. Outerbridge (Geologic Map of the Germantown Quadrangle,1971) as

> Limestone... (1) medium-gray, micrograined, very silty, tabular-bedded, crosslaminated; ... is dominant limestone type in upper part ofunit; (2) medium to light gray, medium-grained, medium-bedded, composed of whole and broken fossils in a crystalline matrix; is dominant limestone type in lower part of unit; (3) medium-gray, weathers buff; medium to coarse grained, crossbedded, ripple marked,... Shale, medium-gray, weathers buff; in partings and sets as much as a foot thich; makes up about half of upper part of unit and about a third of lower part. Siltstone medium-gray, weathers brown, generally thin-bedded....

In addition, it has been proposed that this core be regarded as the "primary regerence standard for stratigraphic units in the eastern Cincinnati region" (Sweet, Harper, Zlatkin, 1974). These geomagnetic polarity results and the calculated mean inclination of stable remanent magnetization is thus derived from the type section for the Cincinnatian Series of North America.

As depositional rates are unknown, no precise age is assigned to any part of the core. Application of the geomagnetic polarity time scale to Ordovician strata must wait for more precise dating of the rock units.

PROCEDURE

The core is split into many segments of unequal length, and missing portions are replaced by equivalent lengths of cardboard. Bob Bartman

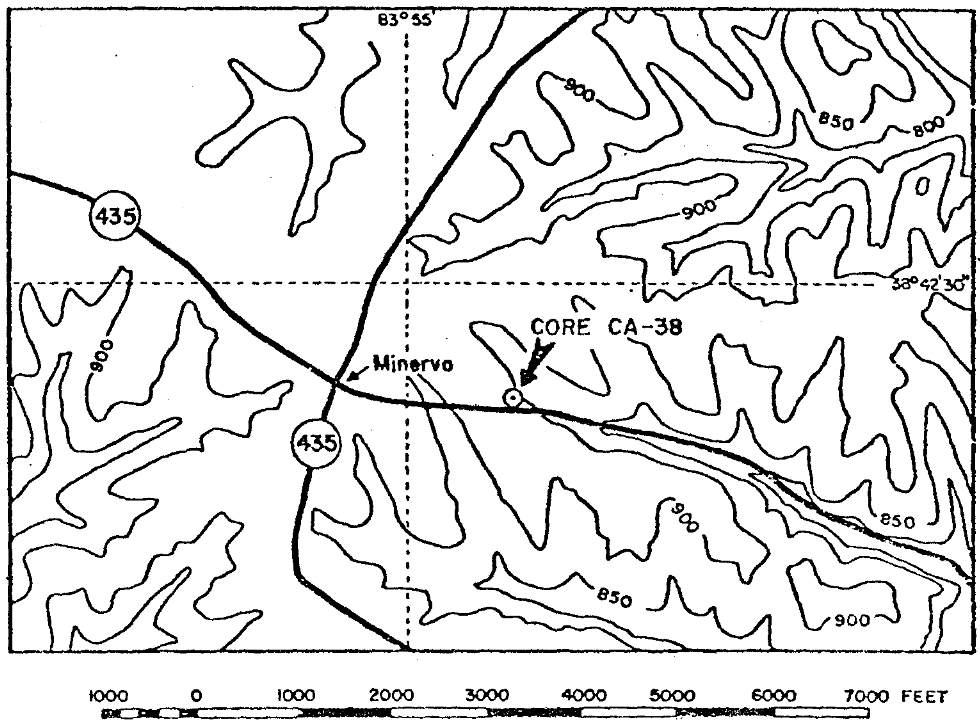


FIGURE 1. A portion of the Germantown, Kentucky, 7.5-minute quadrangle, simplified to show location of the site at which core CA-38 was drilled.

inked a red stripe along the length of the core.so it could be successfully measured, while control could be maintained on the orientation of subsamples. Core segments were measured to the nearest 0.005 foot. The total measurement included these cardboard segments.

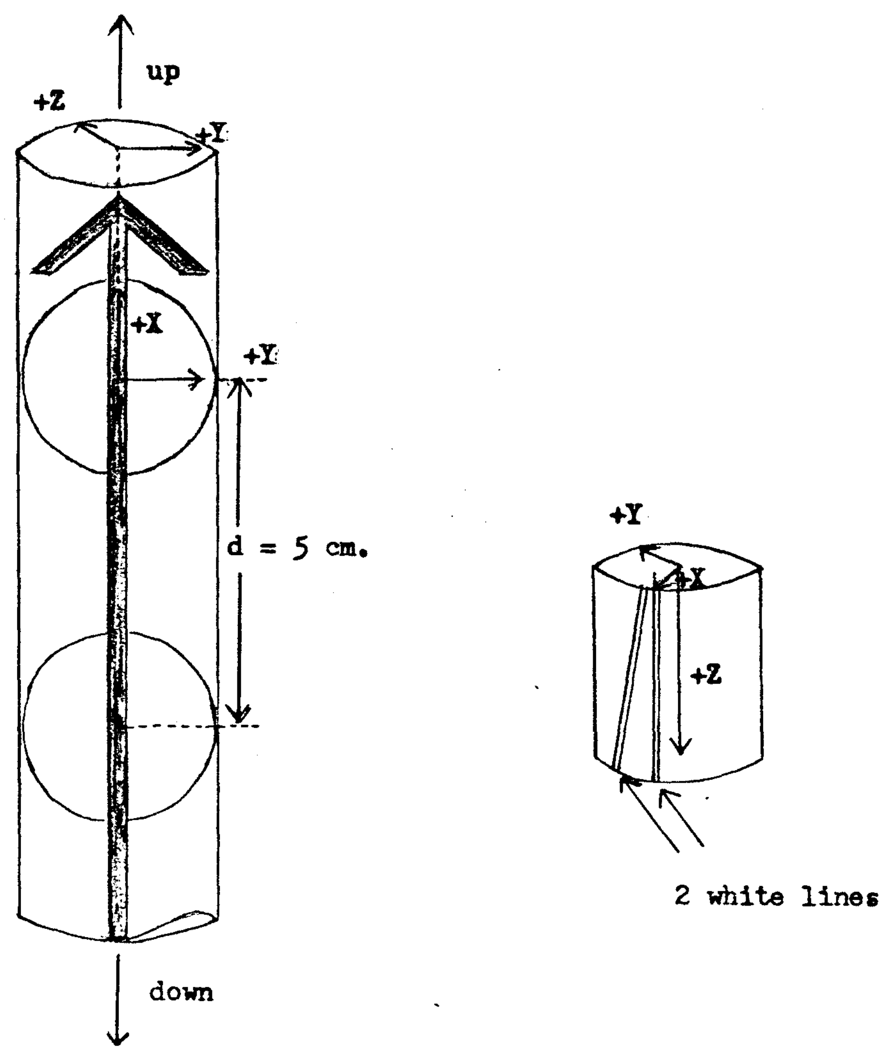
Core segments of sufficient length were placed in the jig, which primarily functions as a guide for a diamond-tipped drill bit so that a one-inch diameter, seven-eighths inch long core can be subsampled for paleomagnetic measurement. Where length permitted, several cores were drilled from one segment. Figure 2 shows a core segment with proper orientation of the coordinate system of the subsample. The spacing between these cores is determined by the jig, such that the distance between centers of the cores is five centimeters. The core segment is placed in the jig such that the red stripe faces toward the subsampling drill bit at all times.

The one-inch diameter cores are then coded. The position of a white stripe, inked along the side of the core perpendicular to the red stripe, indicates which direction is "up" when the core segment was still part of the bedrock. A second white line, inked at an angle to the first so that the "v" points in the direction of the red stripe, assures that all cores will be measured with their positive X-axes in the same direction running up section. Figure 2 also shows how a core is marked in relation to the coordinate system.

Following the coding, the rounded ends of the core are trimmed. The removal of the ends leaves the two white lines to determine the orientation of the core. Every precaution was taken to insure that no core would be mismarked; nevertheless the possibility that some of the core segments themselves were inverted in the boxes before subsampling does exist.

Cores are identified by box, segment, can core number; for example, 70ZA2-5a refers to a core from the second box, the fifth segment in that

Figure 2



The red arrow indicates "up" in the section. The X-axis of each paleomagnetic core is parallel to the red stripe. The two lines on the side of the core indicate that this side was directly above the opposite side when the core was in the ground, and hence that +X points along the "up" direction of the red stripe.

Normal polarity is signified by a positive X-component in the southern hemisphere. Reversals are signified by a negative X-component in the southern hemisphere.

box, and the first core drilled from that segment. The third digit refers to box number, the fourth and fifth digits (if there is a fifth digit) refer to core segment. The letter in small type (a, b, or c) refers to the first, second, or third core drilled from that segment.

The alternating field demagnetizing apparatus is the AC Geophysical Specimen Demagnetizer, model GSD-1, manufactured by the Schonstedt Instrument Company. Magnetic moment determinations for natural remanent magnetization and for magnetization remaining after each 3-axis treatment in alternating magnetic field were carried out on the 3-axis superconducting magnetometer. The value of the alternating field increased either from 100 to 900 Oe. by 100 Oe. intervals, or from 150 to 600 Oe. by 150 Oe. intervals.

The X, Y, and Z-components of each magnetic moment were recorded for both the NRM and for the magnetization after cleaning. The total magnetic moment, J, was calculated for each cleaning by

$$J = (Mx^2 + My^2 + Mz^2)^{\frac{1}{2}}$$

where Mx. My, and Mz are the components of the magnetization vector. Also, Jo for NRM was computed from

$$J_o = (M_{xo}^2 + M_{yo}^2 + M_{zo}^2)^{\frac{1}{2}}$$

where M_{xo}, M_{yo}, and M_{zo} are the components of the natural remanent magnetism. J/J_o was plotted as a function of A.F. Demagnetizing Peak Field, and an experimental determination of the best A. F. treatment could be made by the break in slope of the curve.

For the actual measurement of the moment for natural remanence, a reading of X, Y, and Z components is taken with a sample in the magnetometer. The core is oriented in the mylar tube so that the coordinate axes of the core are measured by the proper sensor in the magnetometer. The core is lowered into the dewar, and the components of the moment are displayed on a digital readout, The core is removed from the dewar and a final reading is obtained. Half of the difference of initial and final readings of each axis sensor output is the value used to correct for drift. Measurements made after each cleaning follow the same procedure.

RESULTS

An experimental determination of the best treatment for removal of secondary magnetization was made by consideration of figures 3and 4 which show the majority of curves levelng out by 600 Oe. Figure 3 shows results for the upper ten feet of core; figure 4 shows results for box2, or the lower ten feet of core. This means primary magnetization is responsible for the directions and intensity of magnetic moments, and values given for the X, Y, and Z-components are reliable enough to use to calculate the magnetization J, and the inclination I.

Secondary magnetization in a sediment is that obtained by a sample after it obtains its primary magnetization when the sediment is deposited. Both primary and secondary magnetization are vector quantities, and added together, make up the natural remanence, NRM. Demagnetization of a sample randomizes the magnetic moments caused by ferrimagnetic grains with low coercive fields. The length of the resultant magnetic moment vector of the NRM decreases with greater rendomization of these moments. By 600 Oe., the magnetically soft remanence vectors are rendomized, hencethe magnetization surviving this treatment is very stable. The best evidence that it is primary is that the mean inclination of the stable remanence is near the inclination in rocks of Ordovician age which have been studied paleomagnetically by A.F. and thermal demagnetization techniques (McElhinny and Opdyke, 1973).

Neither Bartman nor I had sufficient time to carry out detailed thermal

Figure 3

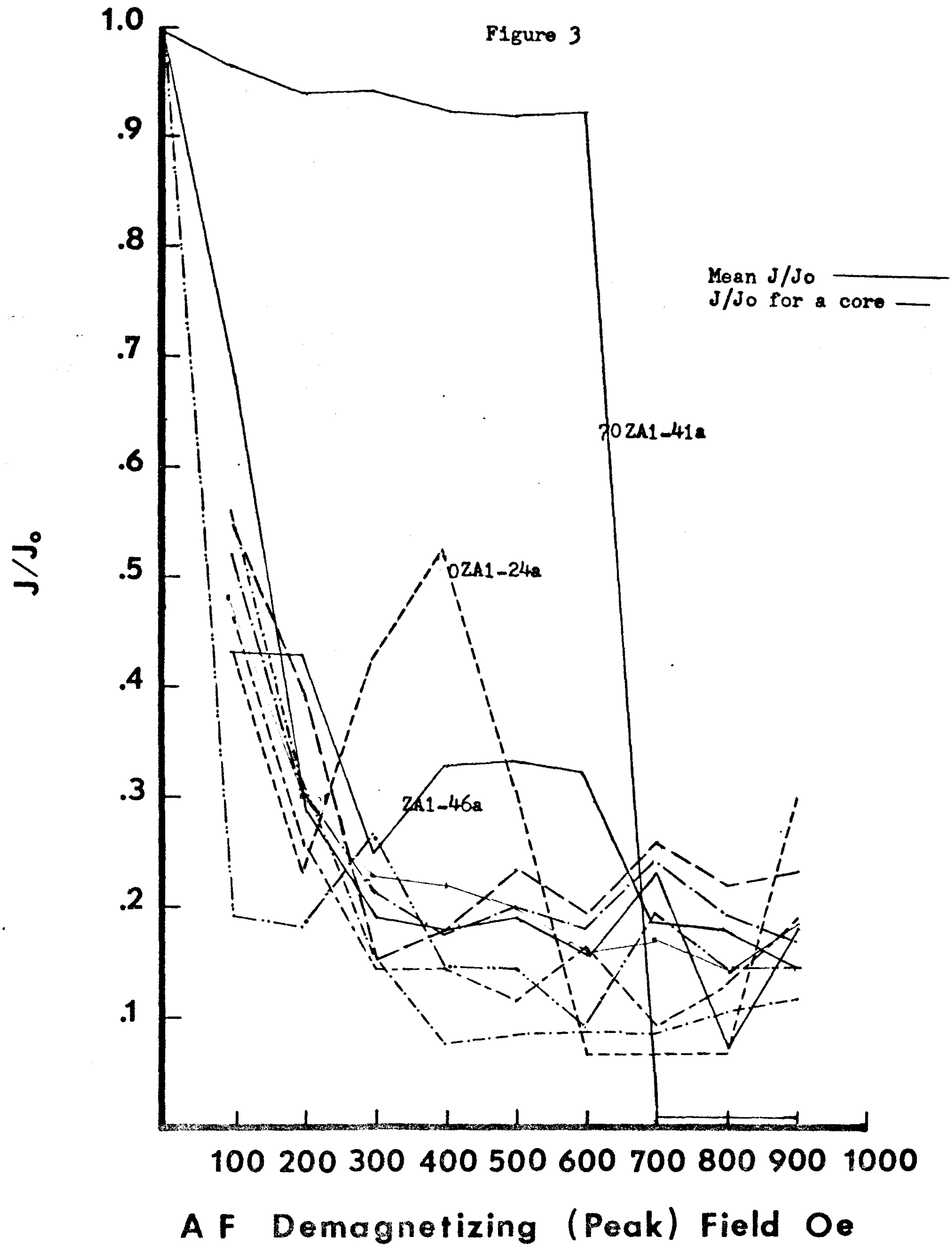
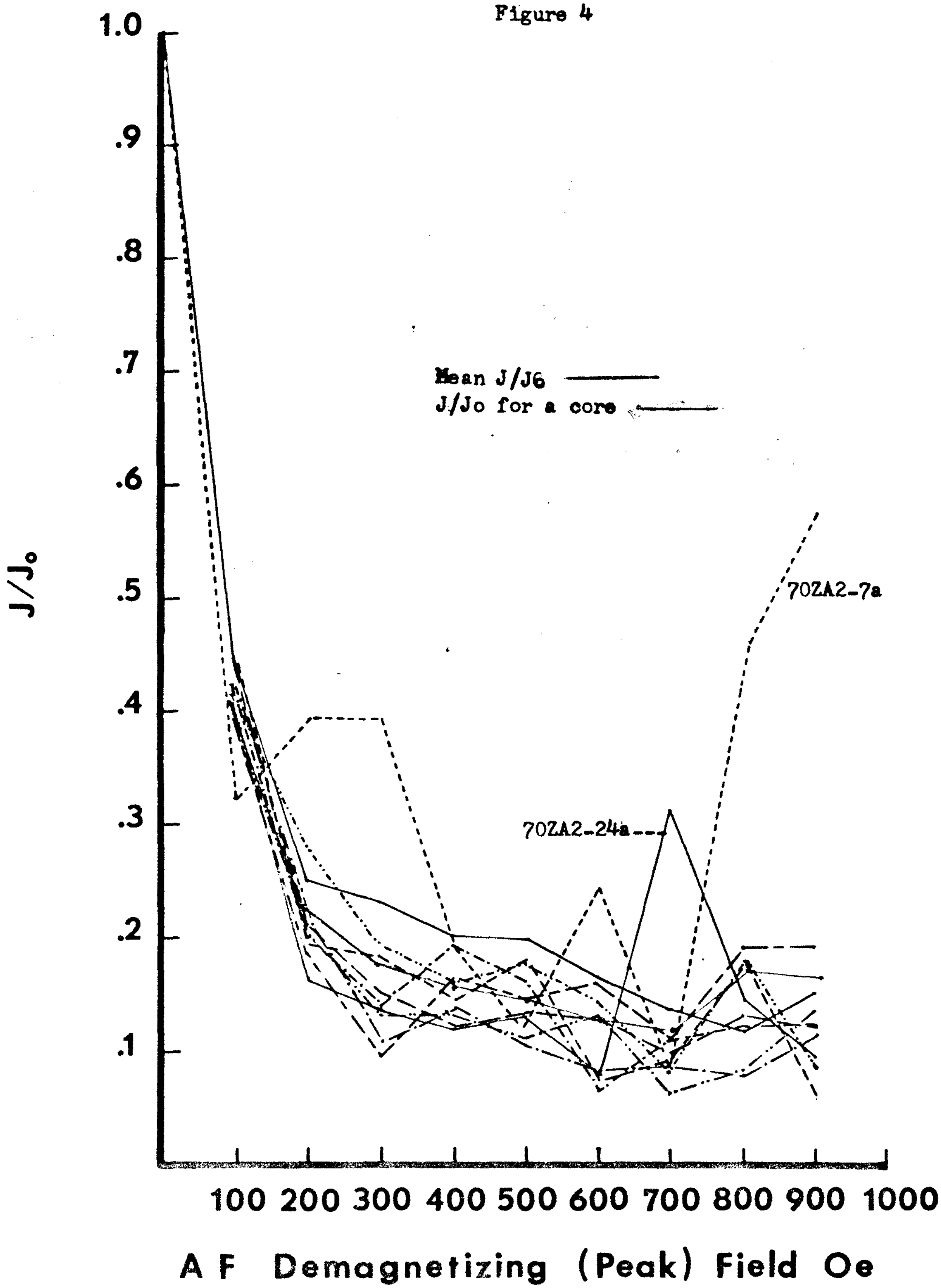

1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
J/Jₒ
Mean J/Jo
J/Jo for a core
70ZA1-41a
0ZA1-24a
ZA1-46a
100 200 300 400 500 600 700 800 900 1000
A F Demagnetizing (Peak) Field Oe

Figure 4


Mean J/J6
J/Jo for a core
70ZA2-7a
70ZA2-24a
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
J/Jo
100 200 300 400 500 600 700 800 900 1000
A F Demagnetizing (Peak) Field Oe

demagnetization studies on the Fairview subsamples. Had we done so, and shown only one ferrimagnetic mineral (hematite is the nost probable cause of the stable remanence) was present; then the fact that we did show the remanence as stable would have established the stable remanence is primary. This study should be carried out in future studies of the Fairview Formation. Recent paleomagnetic studies of limestone of Ordovician age from Scandinavia (Noltimier and Bergstrom, 1976) have shown that the stable remanence is due to hematite.

In figure 3 core 70ZA1-41a shows an anomalous result where a very hard initial magnetization (J/J_o = 0.93) survives A.F. treatment through 600 Oe. This result could be due to magnetic contamination of the tape, but quite possibly it is a real result. A very hard magnetization is one requiring a large alternating field as the coercive force necessary for removal of the saturation IRM, so the magnetization falls to Zero. Perhaps 700 Oe. is this coercive force since J/J_o after 700 Oe. is so very close to zero, The sharp cutoff, however, is suspicicus.

In figure 4, cores 70ZA1-24a, 70ZA1-46a, 70ZA2-24a, and 70ZA2-7a show fluctuations in J/J_o with increasing A.F. demagnetizing field, probably due to successive removal of soft viscous components of alternate polarity. J/J_o for core 70ZA1-24a increases from .23 to .42 to .52 and drops to .30; while J/J_o for core 70ZA1-46a decreases, increases to .33 at 400 Oe., and drops to .19 at 700 Oe. J/J_o for 70ZA2-7a increases at 800 Oe., while J/J_o for core 70ZA2-24a peaks at 700 Oe. For the most part, J/J_o for the cores shows more moderate increases and decreases with increasing A.F. peak field.

Average values for J/J_o were computed for each field. By the graphs it is easily determined where the mean J/J_o lies in relation to the envelope of values. Note that core 70ZA1-41a was not included in the calculation of the mean because it is not certain whether it represents a real result.

All J/J_0 curves begin at 1.0 though not all are represented graphically as such.

The criteria for normal polarity is such that if we imagine a bar magnet along the earth's axis of rotation, the lower end being positive with respect to the end in the northern hemisphere, lines of force proceed from the positive end to the negative. For reversed polarity, the lines of force proceed from the positive end, now in the northern hemisphere to the negative end of the bar magnet in the southern hemisphere. If we stand on the earth's surface in the southern hemisphere during the time of normal polarity, the lines of force point "up" or away from the earth; this direction is indicated by a positive X-component in the subsample. Conversely, during a reversal, the lines of force in the southern hemisphere proceed "down" or into the earth, signified by a negative X-component in the subsample.

Tables 1 and 2 give the X-component and the total resultant magnetization for NRM and three A.F. demagnetization fields, 300 Oe., 400-450 Oe., and 600 Oe. Taken together, 70ZA1-24a and 70ZA1-30a provide the first probable reversal (or the last in geologic time for the forty-foot core) from prevailing polarity. The X-component for the first core changes sign during demagnetization, indicating that the whole core was not measured upside-down and that the residual resultant magnetization vector has actually changed direction, due to removal of a soft downward component acquired in recent times in the northern hemisphere.

70ZA1-34b, 70ZA1-35a, and 70ZA1-35b also indicate a reversal for the same reason. The sign occurs for the X-component at 600 Oe. for 70ZA1-34b. Cores 70ZA1-48a and 70ZA1-52a indicate a field reversal. 70ZA1-52a has a negative X-component for NRM, a positive X-component for 300 Oe., and a negative X-component for 600 Oe. 70ZA2-33a is not a certain reversal

SUPERCONDUCTING MAGNETOMETER OUTPUT

SAMPLE	H=NRM X	H=NRM J	H=300 X	H=300 J	H=400-450 X	H=400-450 J	H=600 X	H=600 J
ZA1-4A	-0.1130	0.348E-05	-0.1010	0.343E-05	-0.0970	0.347E-05	-0.0970	0.330E-05
ZA1-10A	-0.0070	0.159E-06	-0.0020	0.300E-07	-0.0020	0.283E-07	-0.0010	0.245E-07
ZA1-12A	-0.0095	0.161E-06	-0.0010	0.245E-07	-0.0020	0.287E-07	-0.0015	0.308E-07
ZA1-24A	-0.0020	0.755E-07	0.0	0.316E-07	0.0	0.391E-07	0.0	0.500E-08
ZA1-30A	0.0150	0.242E-06	0.0020	0.458E-07	0.0005	0.158E-07	0.0020	0.245E-07
ZA1-31A	-0.0165	0.392E-06	-0.0025	0.112E-06	-0.0075	0.903E-07	-0.0065	0.778E-07
ZA1-32A	-0.0300	0.492E-06	-0.0055	0.903E-07	-0.0080	0.130E-06	-0.0050	0.116E-06
ZA1-33A	-0.0245	0.316E-06	-0.0095	0.123E-06	-0.0060	0.918E-07	-0.0065	0.718E-07
ZA1-34A	-0.0155	0.326E-06	-0.0020	0.594E-07	-0.0025	0.604E-07	-0.0015	0.696E-07
ZA1-34B	-0.0225	0.323E-06	-0.0015	0.472E-07	-0.0025	0.406E-07	0.0015	0.187E-07
ZA1-35A	0.0265	0.423E-06	0.0045	0.652E-07	0.0020	0.320E-07	0.0030	0.364E-07
ZA1-35B	0.0340	0.450E-06	0.0035	0.642E-07	0.0030	0.640E-07	0.0030	0.735E-07
ZA1-36A	-0.0130	0.248E-06	-0.0025	0.596E-07	-0.0030	0.610E-07	-0.0025	0.255E-07
ZA1-37A	-0.0120	0.242E-06	-0.0010	0.548E-07	-0.0020	0.255E-07	-0.0020	0.577E-07
ZA1-40A	-0.0200	0.539E-06	-0.0035	0.115E-06	-0.0040	0.939E-07	-0.0020	0.964E-07
ZA1-41A	-0.1060	0.336E-05	-0.1025	0.316E-05	-0.0990	0.311E-05	-0.0990	0.311E-05
ZA1-41B	-0.0100	0.412E-06	-0.0035	0.977E-07	0.0	0.856E-07	-0.0010	0.461E-07
ZA1-41C	-0.0130	0.407E-06	-0.0020	0.650E-07	-0.0015	0.328E-07	-0.0015	0.743E-07
ZA1-42A	-0.0210	0.350E-06	-0.0040	0.604E-07	-0.0030	0.472E-07	-0.0010	0.403E-07
ZA1-43A	-0.0180	0.316E-06	-0.0040	0.415E-07	-0.0050	0.680E-07	-0.0020	0.255E-07
ZA1-43B	-0.0120	0.193E-06	-0.0040	0.406E-07	-0.0030	0.502E-07	-0.0030	0.339E-07
ZA1-46A	-0.0175	0.233E-06	-0.0035	0.579E-07	-0.0045	0.757E-07	-0.0045	0.750E-07
ZA1-47A	-0.0110	0.182E-06	-0.0020	0.406E-07	-0.0005	0.474E-07	-0.0010	0.592E-07
ZA1-48A	0.0030	0.781E-07	0.0010	0.206E-07	0.0010	0.112E-07	0.0005	0.707E-08
ZA1-52A	-0.0055	0.770E-07	0.0005	0.122E-07	0.0	0.158E-07	-0.0010	0.206E-07
ZA1-52B	-0.0375	0.468E-06	-0.0045	0.684E-07	-0.0055	0.669E-07	-0.0045	0.673E-07
ZA1-53A	-0.0145	0.269E-06	-0.0035	0.534E-07	-0.0055	0.634E-07	-0.0015	0.150E-07

Table 1

SUPERCONDUCTING MAGNETOMETER OUTPUT

SAMPLE	H=NRM X	H=NRM J	H=300 X	H=300 J	H=400-450 X	H=400-450 J	H=600 X	H=600 J
ZA2-5A	-0.0220	0.453E-06	-0.0065	0.113E-06	-0.0035	0.730E-07	-0.0030	0.524E-07
ZA2-5B	-0.0125	0.298E-06	-0.0060	0.106E-06	-0.0040	0.943E-07	-0.0035	0.464E-07
ZA2-6A	0.0250	0.518E-06	0.0025	0.725E-07	0.0020	0.723E-07	0.0030	0.583E-07
ZA2-7A	-0.0005	0.587E-07	0.0010	0.229E-07	0.0005	0.112E-07	0.0010	0.141E-07
ZA2-9A	-0.0115	0.167E-06	-0.0045	0.550E-07	-0.0040	0.522E-07	-0.0010	0.458E-07
ZA2-14A	-0.0320	0.586E-06	-0.0055	0.107E-06	-0.0060	0.837E-07	-0.0015	0.430E-07
ZA2-17A	-0.0250	0.464E-06	-0.0040	0.709E-07	-0.0030	0.559E-07	-0.0030	0.583E-07
ZA2-17B	-0.0115	0.275E-06	-0.0035	0.502E-07	-0.0035	0.502E-07	-0.0020	0.361E-07
ZA2-20A	-0.0290	0.345E-06	-0.0030	0.374E-07	-0.0040	0.474E-07	-0.0020	0.287E-07
ZA2-22A	-0.0180	0.444E-06	-0.0070	0.120E-06	-0.0050	0.986E-07	-0.0055	0.687E-07
ZA2-22B	-0.0120	0.247E-06	-0.0020	0.229E-07	-0.0025	0.406E-07	-0.0035	0.394E-07
ZA2-24A	-0.0280	0.282E-06	-0.0040	0.412E-07	-0.0030	0.332E-07	-0.0010	0.224E-07
ZA2-26A	-0.0255	0.517E-06	-0.0045	0.673E-07	-0.0030	0.671E-07	-0.0010	0.660E-07
ZA2-27A	-0.0145	0.226E-06	-0.0050	0.768E-07	-0.0040	0.453E-07	-0.0040	0.568E-07
ZA2-28B	-0.0205	0.356E-06	-0.0040	0.532E-07	-0.0035	0.394E-07	-0.0020	0.458E-07
ZA2-30A	-0.0190	0.469E-06	-0.0015	0.650E-07	-0.0040	0.894E-07	-0.0025	0.308E-07
ZA2-33A	0.0150	0.158E-06	0.0030	0.374E-07	0.0030	0.335E-07	0.0025	0.287E-07
ZA2-35A	-0.0220	0.448E-06	-0.0050	0.103E-06	-0.0040	0.900E-07	-0.0030	0.735E-07
ZA2-35B	-0.0290	0.453E-06	-0.0040	0.707E-07	-0.0040	0.587E-07	-0.0040	0.539E-07
ZA2-36A	-0.0135	0.387E-06	-0.0055	0.745E-07	-0.0040	0.610E-07	-0.0005	0.552E-07
ZA2-37A	-0.0015	0.269E-07	0.0005	0.866E-08	0.0005	0.500E-08	0.0000	0.373E-13
ZA2-41A	-0.0055	0.118E-06	-0.0040	0.482E-07	-0.0035	0.442E-07	-0.0060	0.618E-07
ZA2-46A	-0.0290	0.638E-06	-0.0060	0.160E-06	-0.0040	0.100E-06	-0.0030	0.906E-07
ZA2-46B	-0.0025	0.403E-07	-0.0010	0.141E-07	-0.0015	0.180E-07	0.0	0.180E-07
ZA2-48A	-0.0115	0.369E-06	-0.0005	0.406E-07	-0.0045	0.689E-07	-0.0015	0.472E-07
ZA2-49A	-0.0135	0.162E-06	-0.0020	0.502E-07	-0.0030	0.391E-07	-0.0020	0.391E-07
ZA2-50A	-0.0240	0.416E-06	-0.0030	0.678E-07	-0.0040	0.600E-07	-0.0040	0.539E-07
ZA2-53A	-0.0240	0.320E-06	-0.0045	0.797E-07	-0.0045	0.680E-07	-0.0025	0.750E-07
ZA3-1A	-0.0310	0.382E-06	-0.0060	0.851E-07	-0.0060	0.687E-07	-0.0045	0.579E-07
ZA3-5A	-0.0285	0.508E-06	-0.0030	0.700E-07	-0.0025	0.552E-07	-0.0005	0.606E-07
ZA3-12A	-0.0030	0.332E-07	0.0015	0.296E-07	0.0015	0.250E-07	0.0005	0.707E-08

Table 2

because there is a chance the core segment may have been inverted. There is no sign change in this core. The X-component for 70ZA2-7a is negative for NRM, and is positive at 600 Oe., so 70ZA2-6a and 70ZA2-7a indicate a change from prevailing polarity.

A certain reversal can be identified with 70ZA2-37a and 70ZA3-12a. The X-component of 70ZA2-37a changes from -0.0015 Oe. to +0.0005 Oe. At 600 Oe. the X-component has decreased in intensity to zero which could mean that the original effects of magnetization in the X-direction have been totally erased so there is nonet moment in that direction. 70ZA3-12a reverses its X-component from negative to positive, and at 600 Oe. has decreased in intensity to +0.0005 Oe.

A period of normal polarity is identified with core 70ZA1-7a, which shows fluctuations in intensity. Cores 70ZA1-24a shows neither a reversal nor normal polarity. Possibly, it represents the time of transition when the earth's magnetic field was changing its polarity from reversed to normal, because the X-component is 0.000 Oe. As these cores gave often erratic results for J/J_0, it is necessary to use caution in interpreting their results.

In figures 5-8, depths to the cores were plotted to the left of the shale percentage scale, so the exact positions of the reversals with respect to the core can be seen. The core was free to rotate within the drill bit, so only one direction is known with any certainty, and that is the positive X-direction, or up-drillhole direction. Therefore the declination, the precision, k, and the accuracy, α_{95} cannot be determined. An inclination and paleolatitude were determined, however, and the longitude of the virtual geomagnetic pole was interpolated.

Ten cores with reversed polarity were chosen at random, and the

Core No.	Core Depth in feet	Polarity
4a	20.35	R
10a	21.30	R
12a	21.85	R
24a	23.18	O
30a	23.84	N
31a	24.03	R
32a	24.28	R
33a	24.54	R
34a	24.75	R
34b	24.91	N
35a	25.11	N
35b	25.28	N
36a	25.55	R
37a	25.83	R

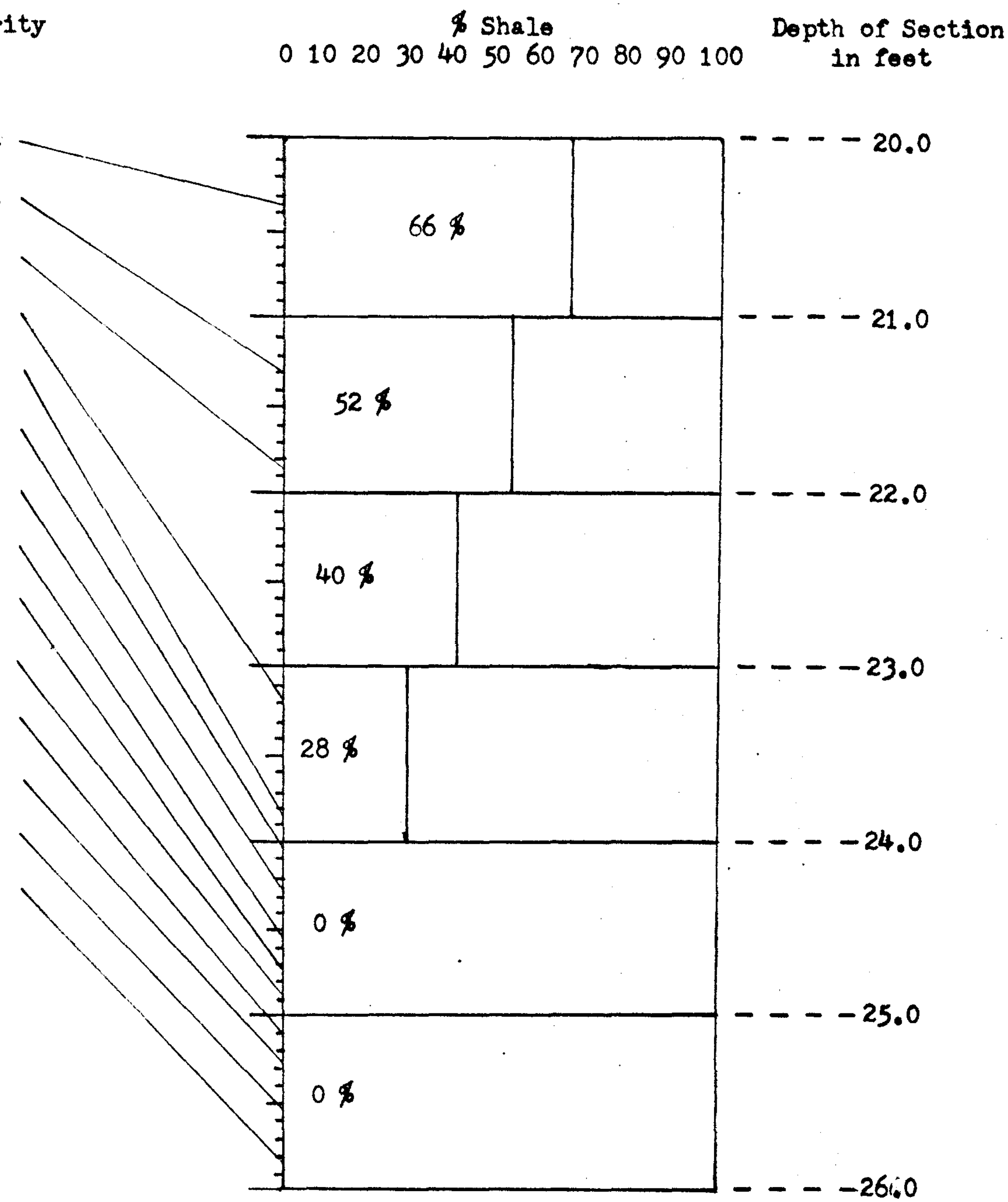


Figure 5

Core No.	Core Depth in feet	Polarity
40a	26.30	R
41a	26.49	R
41b	26.66	R
41c	26.82	R
42a	27.04	R
43a	27.33	R
43b	27.49	R
46a	28.22	R
47a	28.38	R
48a	28.58	N
52a	29.02	R
52b	29.18	R
53a	29.47	R

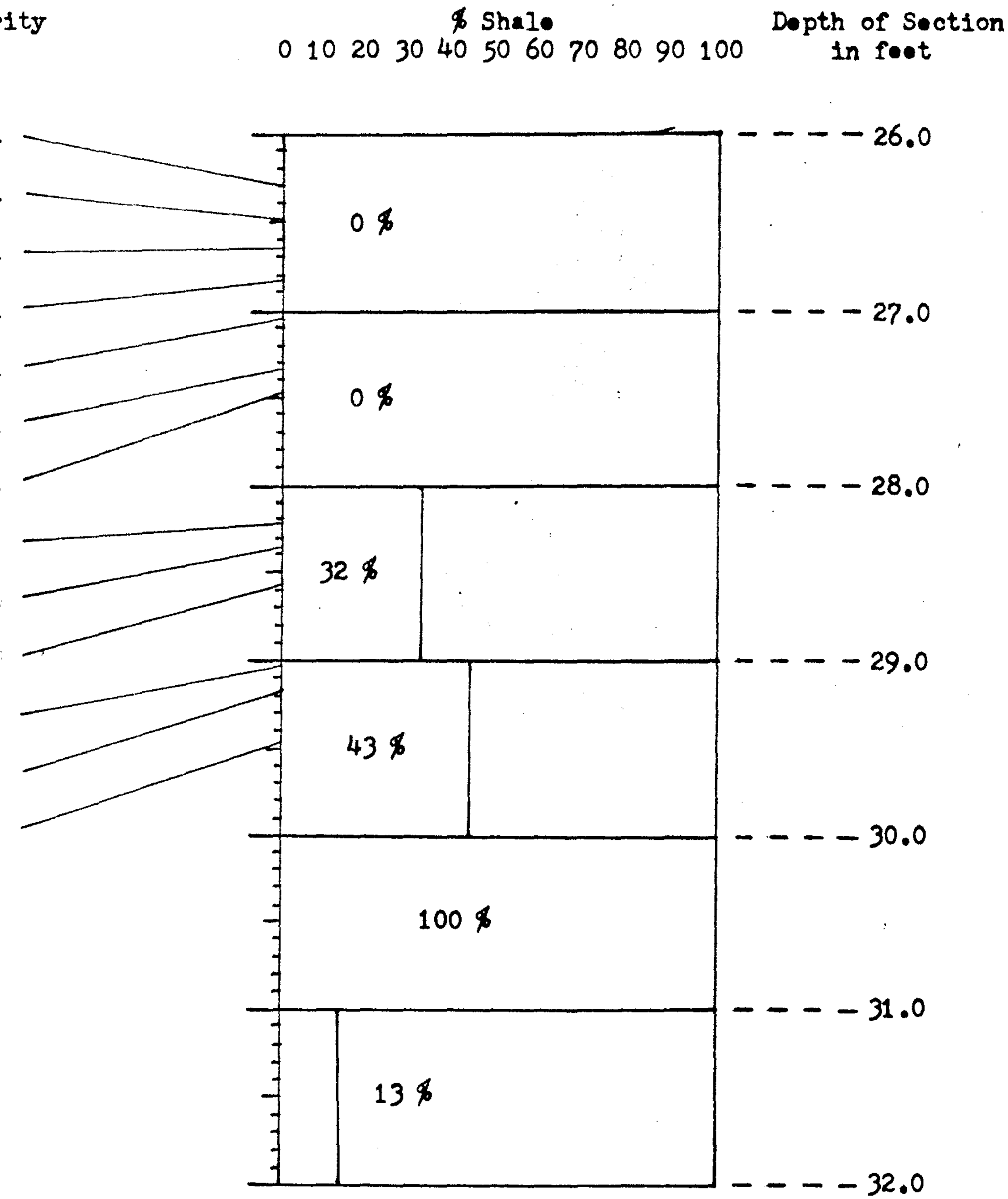


Figure 6

Core No.	Core Depth in feet	Polarity
5a	32.73	R
5b	32.89	R
6a	33.05	N
7a	33.21	N
9a	33.59	R
14a	34.12	R
17a	34.57	R
17b	34.66	R
20a	34.89	R
22a	35.15	R
22b	35.29	R
24a	35.58	R
26a	35.78	R
27a	35.95	R
28b	36.18	R
30a	36.58	R
33a	36.92	N
35a	37.64	R
35b	37.75	R
36a	37.95	R

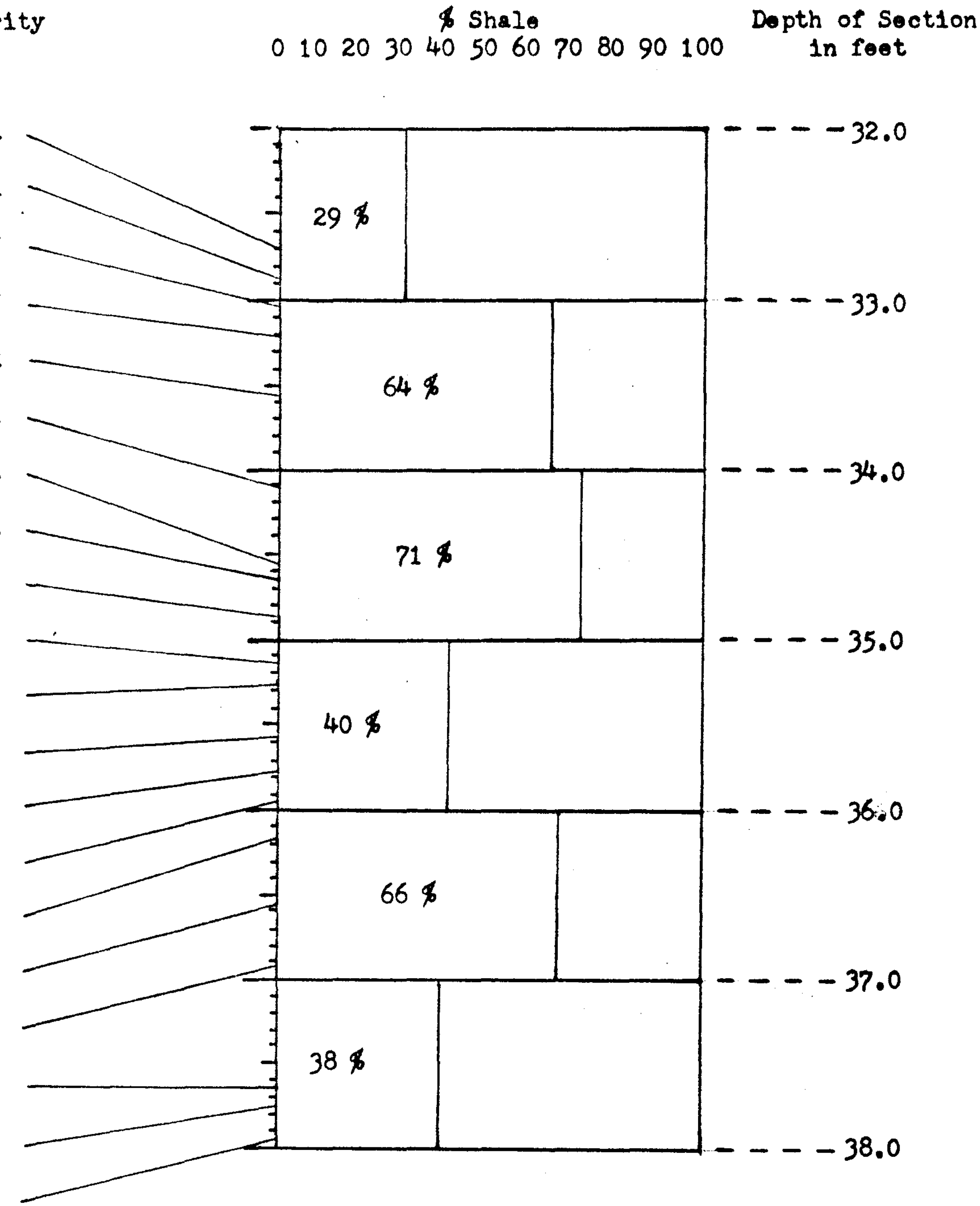


Figure 7

Core No.	Core Depth in feet	Polarity
37a	38.18	0
41a	38.93	R
46a	39.39	R
46b	39.54	N
48a	39.91	R
49a	40.14	R
50a	40.32	R
53a	40.71	R
1a	41.18	R
5a	41.84	R
12a	42.79	N

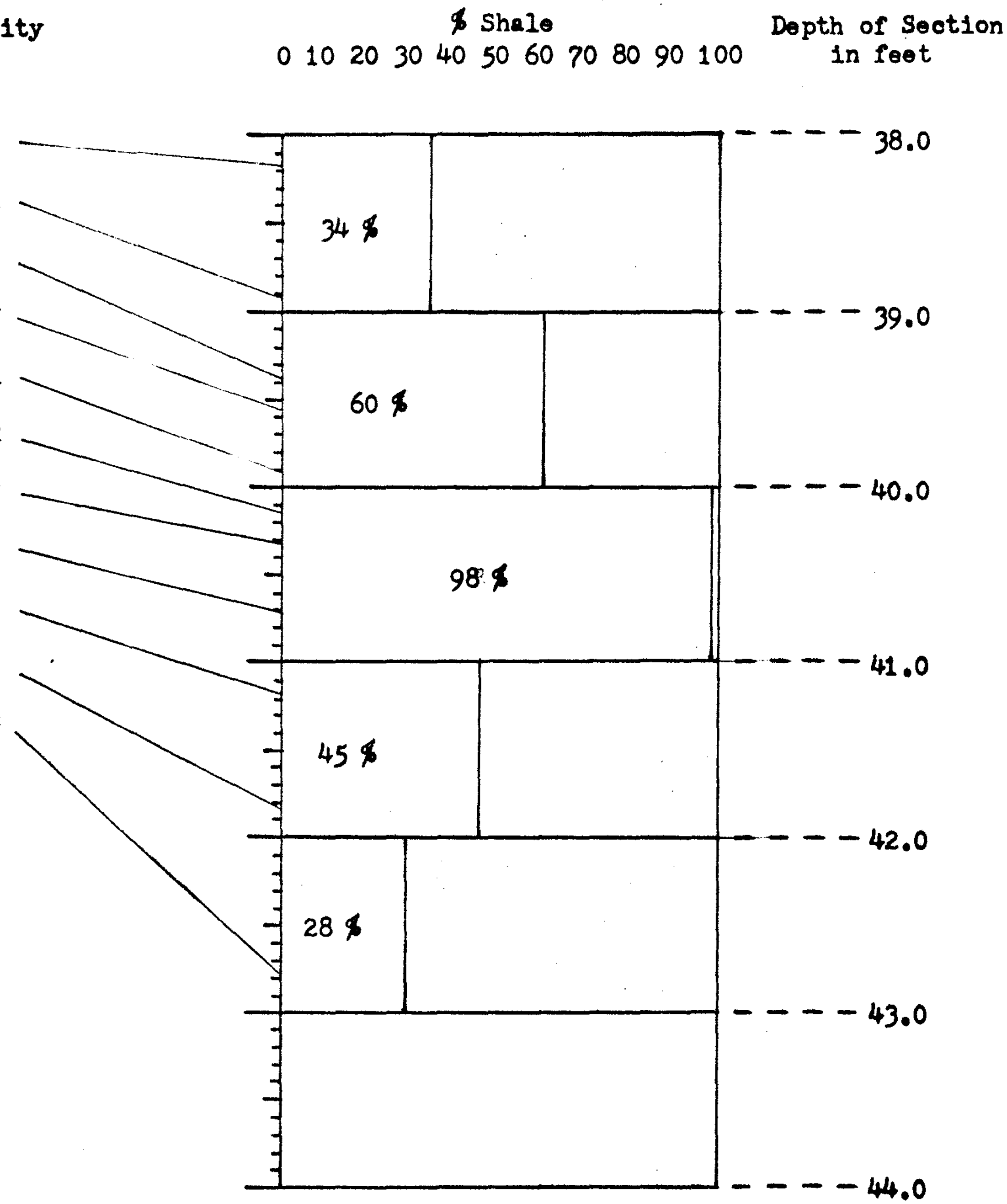


Figure 8

inclination for each core was calculated from the formula[9]

$$I = \arccos(M_x^2 + M_y^2)^{\frac{1}{2}}/(M_x^2 + M_y^2 + M_z^2)^{\frac{1}{2}}$$

where M_x, M_y, and M_z are the X, Y, and Z-components of the magnetic moment, amd I is the inclination of the earth's paleomagnetic field. These ten inclinations were averaged to give a mean inclination of 40.0°. Only eight cores were found to be of normal polarity, and their mean inclination is 12.1°. The average inclination of both normal and reversed polarity is 26.0°. The palaeolatitude was calculated from the dipole formula:

$$\tan(I) = 2\tan(\lambda),$$

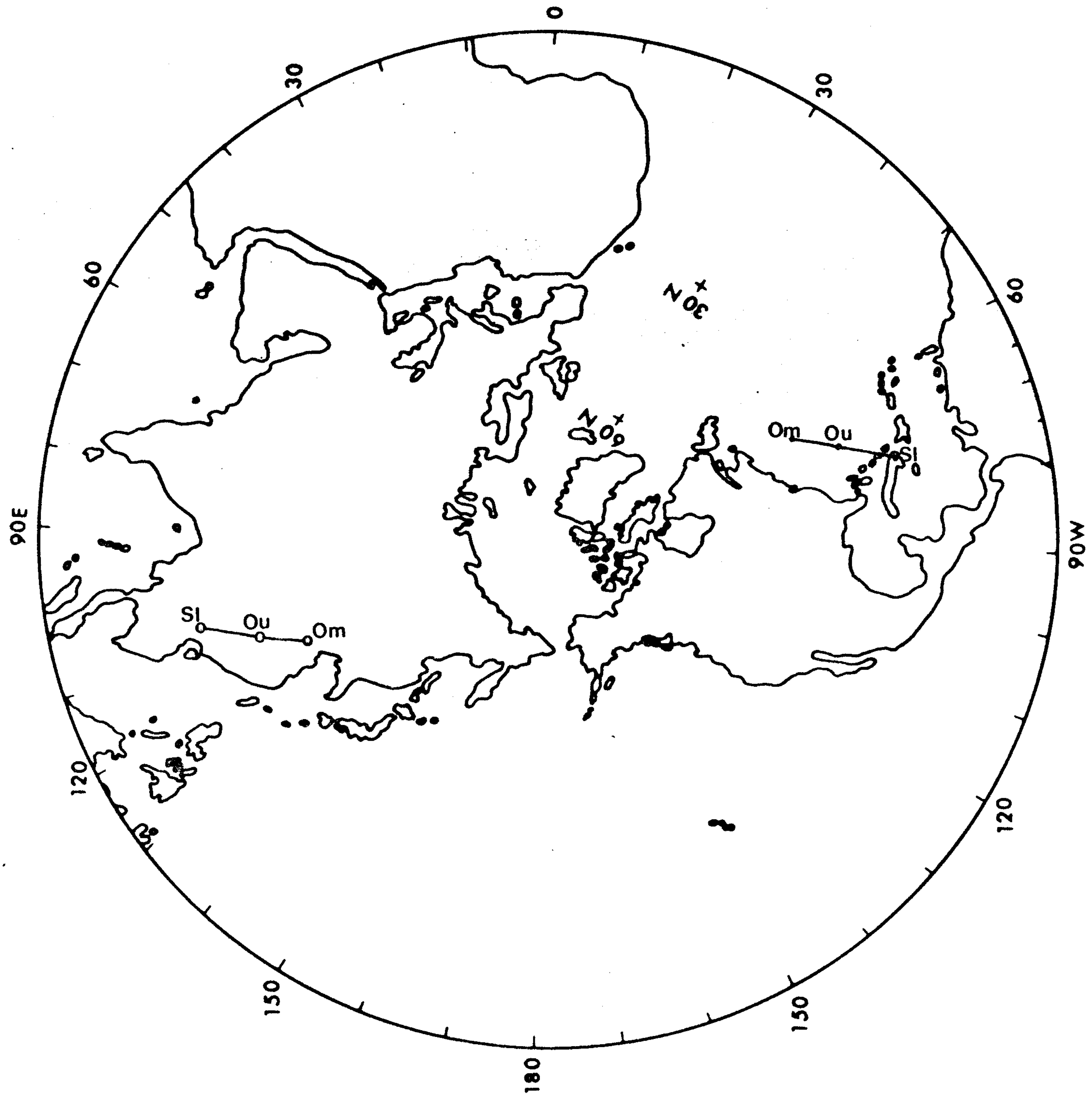
where I is the inclination and λ is the paleolatitude, and found to be 13.7° S. The North American craton was situated in the southern hemisphere during Ordovician time.

Larson and Mutschler (1971) calculated the pole position for the Cambro-Ordovician Colorado Intrusives at 40°S. and 69°W. McElhinny and Opdyke (1973) calculated the pole for the Trenton Limestone (Middle Ordovician) as 36°S., and 66°W.; Opdyke, referenced in McElhinny and Opdyke (1973), calculated the pole for Lower Silurian time (Castanea Formation) as 21°S., 75°W. We interpolate the Upper Ordovician pole at 27°S., 70°W. This puts the paleolatitude of Southern Ohio - Northeastern Kentucky at about 18-20°S.

Plotting paleomagnetic pole position results in curves that look as if the geomagnetic poles themselves wandered through geologic time. Actually the pole positions plotted for the different continents do not coincide with the continents in their present locations. The conclusion is that the continents moved, not that several geomagnetic poles existed concurrently and were moving independently.

If longitude is interpolated between the Middle Ordovician and Early Silurian poles, the result is 70.5°W. The calculated paleolatitude and

Figure 9



interpolated longitude of the Upper Ordovician is plotted in figure 9 with results from Middle Ordovician and Lower Silurian as an apparent polar wander path. The north poles are circles and the south poles are dots. The equator would cross through Ohio during Permian time.

CONCLUSION

McElhinny's statement that "Reversals were infrequent during the Upper Ordovician" has been reevaluated in the light of these results, which indicates a significant number of reversals in that time interval. In the Upper twenty feet of core, one certain reversal occurred in the oldest rock; four probable reversals were found in the upper fourteen feet, and the reversal that could possibly be due to segment inversion is found at approximately 17 feet from the top of the core.

It is left for future investigation to complete the determination of the paleomagnetic pole of the Cincinnatian Series by further sample collection with declination control. By analysis of rates of sedimentation, the magnetic polarity time scale could conceivably be extended. The Upper Ordovician for the time interval represented by this 20 feet of limestone and shale is predominantly a time of reversed polarity, with brief periods of normal polarity constituting the reversals.

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